Cornell University
Center for Advanced Computing

CAC and Stephen Pope

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Turbulent Combustion: Developing Next-Generation Computational Tools

Discover It.

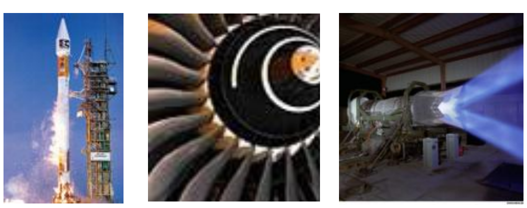
How do you create a more realistic turbulent combustion model to help design engineers increase combustion efficiency and reduce carbon dioxide emissions?

Now.

Stephen Pope, Professor of Mechanical Engineering at Cornell, pioneered the transported PDF method and the *in situ* adaptive tabulation (ISAT) algorithm to speed the computational implementation of combustion chemistry. He is now combining large-eddy simulations of turbulent flow with detailed calculations of chemical kinetics, a computationally demanding task. CAC is providing Professor Pope with parallel computing consulting, and housing and maintaining a dedicated Windows HPC Server 2008 high-performance computing cluster to support his research objectives.

Turbulent Combustion

Industrial engineers are continually seeking to offer cleaner and more efficient turbulent combustion systems for manufacturing, power generation, and transportation in order to speed the economy and at the same time reduce pollution. In response to this challenge, Stephen Pope and his group are developing computational tools for calculating combustion device processes.



Photos courtesy of Rolls Royce and Pratt and Whitney

"In space and aircraft applications, the design of combustors in propulsion systems remains a significant technical challenge," explains Pope. "The usual design and development procedures include both computer modeling and experimental testing. In all of the relevant applications, testing is extremely expensive and time-consuming; and indeed for some space applications, the appropriate conditions cannot be achieved at reasonable cost in ground tests. Because of this, reliable and accurate computer models are continually being sought to increase combustor performance and to reduce both the development costs and the design cycle time."

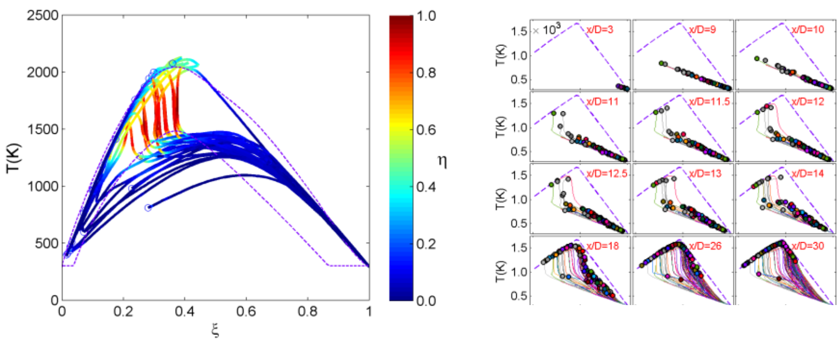
Improved Research

Research Metrics

- Speed: Parallelize and optimize the research application for speed; improve parallel algorithms
- Efficiency: Outsource HPC cluster hosting and management to CAC

Research Challenge

"Our goal is to create user-friendly engineering tools – for example, FLUENT serving as a front end to detailed flame calculations – that will accurately predict behaviors of a given combustion design," said Pope. He explained that an important component of the group's work is to validate their models with HPC against combustion systems that are studied experimentally. The team can easily vary parameters in simulations and look for consequences in measureable factors such as temperature field and exhaust products.



"Computer models are currently used in the design of combustors, but substantial improvements are needed in their accuracy, reliability, and computational efficiency. With the algorithms and methods we develop, an engineer will be able to design combustion equipment more quickly that operates better and less expensively. The cars we drive will be more productive. Electricity generation will be more efficient."

Solution

To facilitate his research on turbulent combustion flows, Pope is applying high-performance computing to FLUENT, the leading commercial application for computational fluid dynamics. Dr. Steven Lantz, senior research associate at CAC, has assisted Professor Pope and his students with the development of code that runs efficiently in parallel on CAC clusters.

"In trying to solve the turbulent combustion equations on parallel machines, we soon encountered an interesting problem," said Dr. Lantz. "We found that the distribution of the workload was badly unbalanced because of the method FLUENT uses to assign parallel tasks. In FLUENT, the workload is distributed based on the geometry of the flow; however, these combustion simulations are dominated by chemical computations. The application was not taking into consideration that some regions of the flow – for example, the core of the flames – involve much more chemistry than others." Accordingly, Pope, Lantz, and several students have been addressing the issue of load balancing during chemistry calculations, which can be an impediment to parallel scale-up on large numbers of processors.

CAC hosts and manages the Combustion and Turbulence Simulator (CATS) cluster for Professor Pope. This cluster has 36 nodes and a total of 144 cores. 140 cores are available for parallel computations, and the other 4 are dedicated to cluster management. The cluster runs the Windows HPC Server 2008 operating system. Pope and Lantz won a Defense University Research Instrument Program (DURIP) grant to fund the CATS cluster.

The Client

Stephen B. Pope

- Sibley College Professor, Sibley School of Mechanical and Aerospace Engineering, Cornell University
- Research in PDF methods, stochastic modeling of turbulence phenomena, direct numerical simulations of turbulence, and computational methods for combustion chemistry
- Wrote *Turbulent Flows* (Cambridge University Press) and has published over 170 research papers
- Consultant to Boeing, ExxonMobil Corporation, General Motors, MIT, Rolls-Royce, and Fluent

The Collaborative Relationship

CAC collaborates with Stephen Pope on the parallel computing aspects of his research and houses and maintains a dedicated cluster for Pope's research group whose combustion research demands high-performance computing.

"The power of high-performance computing allows us to make more accurate calculations than we could otherwise make, so we can precisely determine numerical errors. We are also able to model more complicated flames."

Stephen B. Pope
Sibley College Professor
Sibley School of Mechanical and Aerospace Engineering
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Acknowledgements

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